Switching Magnetic Entities by an Electrical Current

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The information on a computer hard disk, is stored in billions of tiny magnetic entities (or bits) through their magnetization directions. Previously, a magnetic field is always required to reverse the magnetization of a small entity such as that of a bit in a hard disk. It has recently been realized that a current alone of sufficient strength can also perform the feat (or record the bit) without resorting to a magnetic field. This is because the electrons in the current carry spin angular momentum, which in turn can exert a torque to switch the bit.

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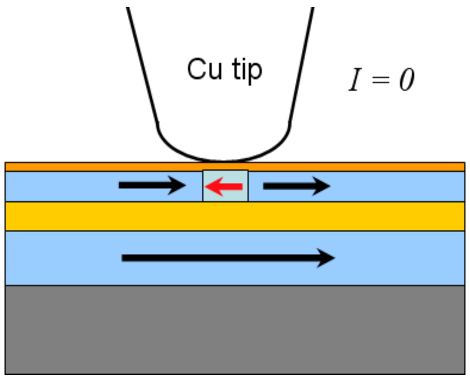

A current is sent through the Cu tip in contact with a magnetic multilayer of Co/Cu/Co, in which the two magnetic Co layers (labeled with black arrows) have different thicknesses. The current causes switching of the magnetic domain (bit) of the thin Co layer under the tip. The domain (bit) can be sensed using a small current of either polarity. The domain can also be reversed (or erased) by sending a *large* current of the *opposite* polarity. No magnetic field is required for either recording or erasing.

Motion of electrons in electrical circuits is usually detected by measuring the current, which is a flow of millions of electrons. The situation is much different in the case of nanoscale objects, called quantum dots whose behavior is dominated by only a few loosely bound electrons. Working in the field of quantum information science, we have shown that it is possible to control the rate at which the electrons escape the quantum dots. For example, we have developed devices such as a Single Electron Transistor (SET) that can be switched on or off with the addition of a single electron. With our collaborators from Bell Laboratories, we have used a special type of SET and detected the motion of individual electrons in and out of a semiconductor quantum dot. The experiment was done at temperatures only a few hundredth of a degree above absolute zero. We measured the output signal from the SET in a coded way and transformed it so we can see the changes in the SET signal in real time. Our group observed sudden changes in the SET output and showed that these changes correspond to individual electrons moving in and out of the tiny semiconductor dot in roughly ten millionth of a second. This is the first time that individual electron flow had been determined via an SET, and is of considerable interest from the standpoint of new quantum device development. This work was published in the May 22, 2003 issue of Nature.

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Education:
Two graduate students (T. Y. Chen and Y. Ji) are instrumental for this week. Y. Ji, after receiving his Ph. D., is now a distinguished research associate at Argonne National Lab. T. Y. Chen is continuing his graduate studies and working on other experiments related to switching by currents. One such experiment on single ferromagnetic layer is described in Physical Review Letters, **93**, 026601 (2004).

Societal Impact:
This experiments demonstrates the proof of concept that a magnetic hard disk can be recorded and read by a current without using a magnetic field. Furthermore, the size of the recorded bits are as small as a few nm, which is less than the smallest bit achievable today, hence higher recording density. This is a new methodology for ultrahigh density magnetic recording.